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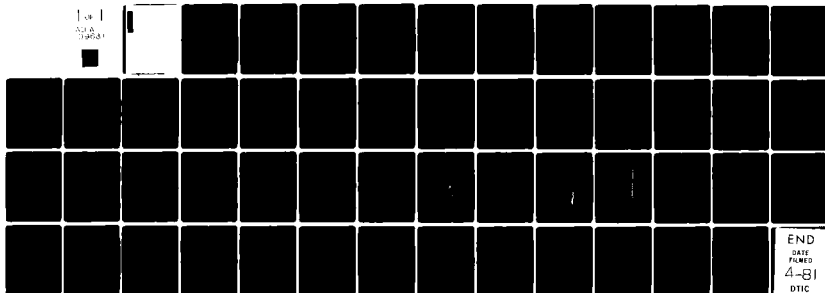
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THE BENTHIC BOUNDARY LAYER EXPERIMENT
ON THE HATTERAS ABYSSAL PLAIN:
CURRENT AND TEMPERATURE OBSERVATIONS

by

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and
L. Armi

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts 02543

February 1981

TECHNICAL REPORT

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Abstract

The near bottom density and velocity fields above the Hatteras abyssal plain were observed with a current/temperature measuring array and a towed-yo-yoing profiler. This report describes the array data and includes details of calibration and data quality. Sources of direction error were diagnosed from vane and compass performance and bearing direction.

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Preface

This volume is the twenty-fifth in a series of Data Reports presenting moored current meter and associated data collected by the WHOI Buoy Group.

Volumes I through XXIV present data obtained during the years 1963-1978, arranged either by year or experiment (see notes).

A data directory and bibliography for the years 1963-1978 has been published, as WHOI Technical Report 79-88.

Volume XXV presents data from the Benthic Boundary Layer Experiment, 1977.

Volume No.	WHOI Ref. No.		Notes	
			Year	Experiment
I	65-44	Webster, F. and N. P. Fofonoff		
II	66-60	Webster, F. and N. P. Fofonoff		
III	67-66	Webster, F. and N. P. Fofonoff		
IV	70-40	Pollard, R. T.		
V	71-50	Tarbell, S. and F. Webster		
VI	74-4	Tarbell, S.	1967	measurements
VII	74-52	Chausse, D. and S. Tarbell	1968	measurements
VIII	75-7	Pollard, R.T. and S. Tarbell	1970	Array Data
IX	75-68	Tarbell, S., M. G. Briscoe and D. Chausse	1973	IWEX Array
X	76-40	Tarbell, S.	1969a	measurements
XI	76-41	Tarbell, S.	1969b	measurements
XII	76-101	Chausse, D. and S. Tarbell	1973	MODE Array
XIII	77-18	Tarbell, S. and A. W. Whitlatch	1970	Measurements
XIV	77-41	Tarbell, S., R. Payne and R. Walden	1976	mooring 592 Saint Croix
XV	77-56	Tarbell, S. and A. W. Whitlatch	1971	measurements
XVI	78-5	Tarbell, S. and A. Spencer	1971-1975	MODE Site
XVII	78-49	Tarbell, S., A. Spencer and R. E. Payne	1975-1977	POLYMODE Array II
XVIII	79-65	Tarbell, S., M. G. Briscoe and R. A. Weller	1978	JASIN
XIX	79-34	Spencer, A., C. Mills and R. Payne	1974-1975	POLYMODE Array I
XX	79-56	Spencer, A.	1974	Rise Array
XXI	79-85	Mills, C. and P. Rhines.	1978	W.B.U.C.
XXII	79-87	Tarbell, S. and R. Payne.	1973	measurements
XXIII	80-40	Tarbell, S. and R. Payne.	1978	POLYMODE Array III
XXIV	80-41	Spencer, A., K. O'Neill and J. R. Luyten.	1976	INDEX

Benthic Boundary Layer Experiment

Introduction

The benthic boundary layer is a region adjacent to the ocean bottom with characteristics distinct from the oceanic interior. Near the bottom it is turbulent, and the resultant mixing is seen as a bottom layer homogeneous in salinity, potential temperature and turbidity. Figure 1 shows a typical CTD profile. This layer is the benthic analog of the atmospheric boundary layer and may be similar to the oceanic surface mixed layer.

In a previous study, Armi and Millard (1976) described boundary layer density profiles taken in the western North Atlantic as part of the Mid-Ocean Dynamics Experiment (MODE). They found that simple mixed layers generally occurred over the Hatteras abyssal plain, while irregular structures, commonly with multiple layers, occurred near rough topography. In a short time series at the edge of the plain they observed a doubling of the mixed layer height in less than a day. The Hatteras abyssal plain was chosen for the location of the intensive benthic boundary layer experiment described here both because of the previously observed simple structures and because the interior flow in this area has been extensively studied (cf. Mode Group, 1978; Briscoe, 1975).

This data report is a companion to the paper of Armi and D'Asaro (1980) and the Ph.D. Thesis of D'Asaro (1980). Armi and D'Asaro (1980) describe the observed variability. A bottom mixed layer is almost always present, but varies in height from 5 to 60 meters, with dominant time scales of several days and longer, and space scales of 10 km and larger. Multiple mixed layers and benthic fronts are seen. D'Asaro (1980) discusses the velocity observations in more detail. High frequency velocity fluctuations appear to be due to bottom generated turbulence. The turbulence, so measured, intermittently fills the entire mixed layer. Near-inertial velocity fluctuations are used to compute the flux of internal wave energy into the mixed layer.

Description of the Experiment

This experiment was designed to measure the density and velocity structure in both space and time near the ocean bottom. A 3-month time series, May 18, 1977 to August 18, 1977, of velocity and temperature was measured by two bottom moorings (Figure 2) deployed near 28°30'N, 70°30'W by the Moored Array Project of the Woods Hole Oceanographic Institution (WHOI). The Hatteras abyssal plain is extremely flat with a slope of only 20 cm/km over hundreds of kilometers (Bush, 1976). Mooring A (WHOI 621) contained vector-averaging current meters spaced so as to span the mixed layers seen by Armi and Millard (1976). Note that instruments 1 and 2 are separated by 20 m, while the other instruments are separated by 10 m. Each instrument recorded vector average velocity and average temperature every 7 1/2 minutes. In addition, the bottom six instruments measured the average differential temperature between the top and the bottom of the instrument case (1.74 m), as described by Dean (1979). Mooring B (WHOI 622), 4.3 km to the east, contained a single vector-averaging current meter measuring average velocity and temperature every 7 1/2 minutes. A summary of moorings is provided in Table 1.

Three spatial surveys of the boundary layer were made, using a towed CTD package. The first was made on cruise KNORR 66 and the second two on cruise OCEANUS 31. Moorings A and B and a third bottom-moored beacon, C, formed an acoustic navigation net (Phillips *et al.*, 1979). By using acoustic navigation the ship and an instrument package could be located to within 10 m with respect to the moorings. Loran C was also used and provided navigational data outside the acoustic range.

A photograph of the instrument package and a preliminary description of these experimental results can be found in the paper by Armi (1978). A Neil Brown conductivity, temperature and depth profiler (CTD); a nephelometer built at the Woods Hole Oceanographic Institution; a General Oceanics rosette water sampler; an acoustic transponder (AMF acoustic release); and a Benthos pinger were enclosed in a protective frame which was lowered

from the ship. The bottom pinger and a precision depth recorder were used to bring the instruments to within 2 m of the bottom. Actual bottom pressure was determined by occasionally setting the instrument package gently on the bottom. The bottom pressure was always 5555 dbar. The CTD and nephelometer data were available in real time on the ship.

Data Processing

Current Meters

The data from the instrument tapes were transcribed to 9-track magnetic tapes, converted to scientific units, edited to remove launch and retrieval transients and bad points, and linearly interpolated across missing or erroneous data cycles. See the section on VACM calibration for details of further modification of temperature data.

WHOI data are identified by a mooring number and a sequential instrument number (e.g. 6223 is the third instrument down on mooring 622). A letter indicating an edited version, and a number indicating the sampling or averaging interval are appended (e.g. 6223A450 is an edited data series with a data point every 450 seconds).

Low passed versions of data series were formed for use in the stick plots and progressive vector plots. The data were passed through a Gaussian filter with a 24 hour halfwidth, and then subsampled once per day. Such data have 1DG24 appended to the data name.

Vector Stick Plots

The 24-hour averaged current components are plotted as individual vectors along a time scale. The vector orientation is such that east is upwards on the page in Figure 3. (North is upwards in Figures 6 and 7.)

Spectra

The horizontal kinetic energy (HKE) and temperature are displayed as spectra in Figure 4. Spectra for all 7 instruments on mooring A are shown. The spectral line for the thermistor on instrument 7 is not shown below 1 cph as it was an internal thermistor, unlike the other six. The HKE spectrum is half of the sum of the spectra of the east and north components. It has the advantage of not being tied to a particular coordinate system.

The spectra are all one-sided, i.e., the area under the spectrum is equal to the variance of the original record. The plots are all log-log hence are not 'variance preserving' i.e., the contributions of various frequency bands to the total variance are not in proportion to the displayed areas.

TIMSAN, the WHOI program (Hunt, 1977) used to produce the spectra breaks the data series into 50% overlapped pieces, computes the Hanned periodogram of each piece, and averages these. The plotted spectra are the average of 38 pieces with 600 points per piece. The spectra are additionally averaged in increasing groups at the higher frequencies to prevent having to plot thousands of points; this gives few degrees of freedom (d.o.f.) at the lowest frequencies, many at the highest frequencies. The 95% confidence limits are shown on one of the plots.

Statistics

Statistics for variables measured by the current meters are presented in Table 2. The temperature values for mooring 621 reflect the offsets from Table 3; the values for mooring 622 do not. Mean, standard error, variance, kurtosis, skewness and extrema are given for all the variables, east and north covariance, correlation and other statistics are given for the vectors. For reference, note that a Gaussian random variable would have a kurtosis of 3 and a skewness of zero.

See volume XVII (POLYMODE Array II) of this series for a more detailed discussion of these parameters.

Progressive Vector Plots

Based on a daily averaged time series, the current vectors are placed tail-to-head so as to show the path that a perfect particle in a perfectly homogeneous fluid would have traveled. Flow regimes and low frequency behavior show up well on this type of plot. The plot in Figure 5 begins with an asterisk, every other day boundary is marked with a tick and every fourth day is annotated.

Composite Plots

Composite plots of velocity and potential temperature data from mooring A (mooring 621) are shown in Figure 6a-e. Panels 1 and 2 (top two panels) show north and east velocity components, vector averaged and recorded every 7 1/2 minutes. The zero for each instrument is offset as indicated. Rotor stalls are shown as horizontal lines at zero velocity. Panel 3 shows 1-day mean vector velocities from each instrument plotted daily. The origin of the vector gives central time and height off bottom. Data at 75 m are interpolated from adjacent instruments. Panel 4 shows differential temperature (difference in temperature between the top and

the bottom of the 1.74-m instrument case) for instruments 2-7. Flat traces correspond to no differential temperature (i.e., the instrument is in a mixed layer). The plot for each instrument is offset vertically, corresponding to its height off bottom as indicated on the left-hand scale. Panel 5 shows 5 m°C time/height isotherms of potential temperature linearly interpolated for each data cycle. No isotherms are plotted below the bottom instrument (15 m off bottom). The peculiar step structure on May 22, for example, results from linear interpolation. Panel 6 shows potential temperature/time plots for all seven instruments. Since potential temperature increases upward, the top trace corresponds to the top instrument, and the bottom trace to the bottom instrument. Mixed layers are shown by merging of adjacent potential temperature lines. Times and duration of CTD stations are shown above the bottom time axis. K indicates KNORR 66 stations; others are OCEANUS 31 stations.

A similar composite is shown for mooring B (mooring 622) in Figure 7a-e. Panels for differential temperature and height isotherms do not apply to this single instrument.

VACM Calibration and Data Quality

Temperature

The measured VACM temperature variations have a precision of better than a millidegree ($\pm 1 \text{ m}^\circ\text{C}$). The absolute temperature calibrations, however, have an accuracy of about 5-10 millidegrees (Payne, et al., 1976). The VACM temperatures have been calibrated in situ as follows: CTD measurements of the bottom mixed layer reveal it to be almost always homogeneous in potential temperature to within a millidegree. Whenever a given instrument showed a constant differential temperature it was assumed to be in a mixed layer. Whenever two adjacent instruments were in a mixed layer they were assumed to be measuring the same potential temperature. Over a period of 3-4 years VACM 5 has had a low temperature calibration drift of $1 \text{ m}^\circ\text{C}/\text{yr}$ (R. Payne, personal communication); the temperature measured by VACM 5 was used as a reference. For example, on 30 July instruments 5, 6 and 7 were in a mixed layer; thus the temperatures of 7 and 6 were shifted until they agreed with 5. In addition, instrument pairs that showed temperature inversions greater than $.5 \text{ m}^\circ\text{C}$ for longer than 40 minutes were shifted to remove the inversion. There were sufficient mixed layers, some detached from the bottom, to provide a consistent potential temperature calibration for all the VACMs on mooring 621. For the deeper instruments enough mixed layers were present to determine both an offset and a linear drift. The offsets used at the beginning and the end of the experiment are shown in Table 3.

Several CTD stations were made within 50 meters of mooring 621; these stations were used to fix the VACM temperatures with respect to the CTD potential temperatures. For the upper instruments, the CTD stations were also used in the relative temperature calibration. The final VACM potential temperatures are $1 \text{ m}^\circ\text{C}$ colder than the CTD potential temperatures for the first CTD survey, and $1 \text{ m}^\circ\text{C}$ warmer for the second and third. The potential temperature from the 7 VACMs of mooring 621 and the 2 CTDs should be consistent with each other to within $2 \text{ m}^\circ\text{C}$.

Velocity

The VACM measures current speed with a Savonius rotor. After recovery of the instruments on mooring 621, they were individually calibrated in the W.H.O.I. flume as described in Appendix A. The new values of $a = 39.44$, $b = 1.3$ were used to decode the velocities for all of the instruments.

The VACM measures current direction with a nearly neutrally buoyant vane. Vane angle, the orientation of this vane relative to the instrument case and compass angle, the orientation of the instrument case relative to north are each digitized to the nearest 2.8° and summed to form the instantaneous current direction, bearing angle. Every 450 seconds the vector average north and east components of velocity, and the latest values of vane angle and compass angle, are recorded.

All 8 VACM instruments used in this experiment performed well, giving complete records of velocity and temperature, with no obvious recording errors. Some measured direction errors and resultant velocity errors were discovered and are discussed below.

Direction error

The third panel of figure 6 shows 1-day mean velocity vector for each instrument as a function of time. A persistent shear is seen between the instruments at 45 and 55 m from early June to mid-July. Figure 8 displays the same data with the mean velocity, obtained by averaging all the instruments at each time, subtracted and the coordinate system rotated so that the mean velocity is horizontal pointing right. The velocities measured at 45 m and 85 m are seen to have a persistent bias to the right of the mean; those at 55 m and 65 m are biased to the left of the mean. The observed biases are equivalent to roughly 10° differences in the measured current direction between instruments. The pattern persists for roughly 40 days, with no corresponding feature in the observed temperatures (bottom panel of figure 6); the pattern then abruptly disappears on July 20.

Figure 9 plots the orientation of mooring 621 in mid-July, as measured by the compasses in each of the top 4 instruments. The mooring is relatively steady except for two rapid rotations occurring at about 0000 and 2000 on July 19, the same day that the persistent shears described above disappear. This is strong evidence that these shears are due to an error in the VACM measurement of current direction.

The vane and compass angle records are examined below. None of the errors found appear sufficient to explain the observed error in direction. The measured VACM directions must therefore be assumed to have systematic and time variable direction errors of unknown origin and magnitude up to 5° . These errors may also be present in other VACM data.

Vane performance

Vane performance was good, except for instrument 6213 in which a slight stickiness developed in the vane. This stickiness can be seen in several diagnostic tests.

Figure 10 shows the vane angle as a function of time for all instruments at the start, May 18, and end, August 18, of the experiment.

Instrument 6213 looks similar to the other vanes at the start of the experiment, but by the end of the experiment shows much less variation, presumably due to a slight mechanical binding in the vane bearings. The vane record for instrument 6213 tends to remain fixed for several data cycles. A useful measure of this tendency is stickiness S defined by

$$S_i = \text{number of samples with no change} \\ \text{from previous sample in a given} \\ \text{interval for instrument } i$$

In this experiment in which several instruments are moored nearby, a more useful related statistic is the relative stickiness R_i

$$R_i = \frac{S_i - \bar{S}}{\bar{S}}$$

where \bar{S} is the average of S_i over all the instruments. If $R_i > 0$ the i^{th} instrument is stickier than the average; if $R_i < 0$ it is less sticky. Table 4 gives R_i averaged over 10 day intervals for each instrument. Instrument 6213 stands out as abnormally sticky starting in mid-June.

Compass performance

The compasses in this experiment generally performed well. Laboratory tests, however indicated that the compass on instrument 6214 was somewhat sticky. One of the standard precruise VACM compass checkout tests is to deflect the compass needle with a small magnet, remove the magnet and then allow the compass to come to rest. This test is repeated and the variability of the final compass position is observed. If this variability is large the compass bearings may be abnormally sticky.

Table 5 tabulates the results of this test for each of the mooring 621 instruments, through several checkout tests. For each set of tests the number of times the compass stopped 0, 1, 2, 3, 4 and 5 bits away from the mean position is tabulated. Generally the compass stops within 1 bit of the mean. Some instruments, for example, 6212 have compasses which return repeatedly to the same position within one bit. Instrument 6214, however, shows deviations up to 5 bits in a pre-cruise test, and up to 2 bits in post-cruise tests. It is tempting to attribute the direction difference found in instrument 6214 to this sticky compass. However instrument 6211, which gives a similar direction to 6214, has one of the least sticky compasses according to the laboratory tests. Compass stickiness, as well as it can be measured, does not appear to account for the observed direction error.

Bearing-Direction

A useful diagnostic time series is the difference between bearing, the instantaneous current direction recorded every 450 seconds, and direction, the vector mean current direction averaged over 450 seconds. Bearing-direction is plotted in Figure 11 for 3 selected intervals, along with the speed from instrument 6211.

At the start of the record, Figure 11a, bearing-direction shows a fairly uniform jitter of about 1.5° , which is quite small for the difference of two time series digitized to 2.8° . Bearing and direction are seen to agree well. At the end of the record, Figure 11c, bearing-direction for instrument 6213 shows a much larger deviation, and a lack of high frequencies. This can be attributed to the sticky vane in 6213, which, although its effect may be partially averaged out in east and north, shows up strongly here in the difference between the averaged and unaveraged current orientation.

Figure 11b shows bearing-direction during a period of high speed. The variance of the time series is seen to increase when the current speed is greater than 13 cm/s. This suggests that additional noise is being introduced into the vane motion, at these speeds, possibly due to mooring motion. Ruddick (1977) finds a similar behavior.

The end of Figure 11a and the beginning of Figure 11c are periods of low speed. Bearing-direction is seen to be highly variable during this time. This may be due either to poor vane response at low speed or a large high frequency variance in actual current direction in the absence of mean currents. Note that when the rotor is stalled, direction is not defined and bearing-direction is plotted as zero.

Bearing-direction for instrument 6215 shows a large spike on August 17. This is due to a wild value of vane at this time.

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Table Captions

Table 1	Summary of mooring information
Table 2	Statistics on current meter data
Table 3	Table of offsets applied to temperature data from instruments on mooring A
Table 4	Vane stickiness values
Table 5	Summary of compass-variability test

Table 1

Mooring Locations and Durations

Mooring #	621	622
Date Set (1977) (Cruise KNORR 66)	17 May	18 May
Date Retrieved (1977) (Cruise OCEANUS 31)	18 Aug	18 Aug
Location deg. min N	28 31.0	28 31.0
deg. min W	70 28.5	70 24.8
Bottom Depth (m)	5453	5453
Float Depth (m)	5328	5403

Moored Instrument Data Summary

(93 days of data, from May 18-Aug 18 1977)

Record #	Depth (m)	Height above bottom (m)
6211	5368	85
6212	5388	65
6213	5398	55
6214	5408	45
6215	5418	35
6216	5428	25
6217	5438	15
6221	5418	35

Table 2a

```

*****
** 62118450      ** 17761 POINTS FROM 77- V -18 TC 77-VIII-18
INST. V-0325 DEPTH 5368 M. UNITS = MM/S , DEGREES CELSIUS
VARIABLE ----- EAST ----- NORTH ----- SPEED ----- TEMPERATURE
MEAN      =      42.798      -2.300      73.087      2.184
STD.ERR.  =      .400      .306      .238      .148E-3
VARIANCE  =    2842.000    1668.140    1005.382    .388E-3
KURTOSIS  =      2.586      2.428      2.607      6.810
SKEWNESS  =      -.186      -.400E-2      .407      .852
MINIMUM   =    -116.287    -110.424    20.000      2.138
MAXIMUM   =     167.435     124.599     177.602     2.373
-----EAST & NORTH----- * * * * *
COVARIANCE =     64.606 *
CORR. COFF. =     .297E-1 *
ORIENTATION =     86.859 *
MAJAX      =     53.344 *
MINAX      =     40.799 *
ELLIP      =      .235 *
*****

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*****
** 62128450      ** 17761 POINTS FROM 77- V -18 TO 77-VIII-18
INST. DT-5104 DEPTH 5388 M. UNITS = MM/S , DEGREES CELSIUS
VARIABLE ----- EAST ----- NORTH ----- SPEED ----- TEMPERATURE
MEAN      =     42.491      3.758      73.039      2.171
STD.ERR.  =      .398      .319      .249      .149E-3
VARIANCE  =    2809.184    1803.403    1097.477    .397E-3
KURTOSIS  =      2.591      2.351      2.604      2.339
SKEWNESS  =      -.187      -.157      .451      .877E-1
MINIMUM   =    -108.405    -111.090    20.000      2.126
MAXIMUM   =     171.272     116.111     176.827     2.231
-----EAST & NORTH----- * * * * *
COVARIANCE =     307.277 *
CORR. COFF. =      .137 *
ORIENTATION =     74.287 *
MAJAX      =     53.811 *
MINAX      =     41.436 *
ELLIP      =      .230 *
*****

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Table 2b

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*****
** 62138450      ** 17761 POINTS FROM 77- V -18 TO 77-VIII-18
INST. DT-5117 DEPTH 5398 M. UNITS = MM/S , DEGREES CELSIUS
VARIABLE ----- EAST ----- NORTH ----- SPEED ----- TEMPERATURE
MEAN      =      41.464          3.193          72.238          2.104
STD. ERR. =       .387          .318          .233          .155 -3
VARIANCE  =    2665.302        1791.616        968.038          .426 -3
KURTOSIS  =       2.729          2.390          2.702          2.120
SKEWNESS  =      -.322          -.168          .401          -.133 -1
MINIMUM   =    -114.371        -108.820          20.000          2.114
MAXIMUM   =     168.671        119.585          176.814          2.223
-----EAST & NORTH----- * * * * *
COVARIANCE =     266.713      *
CORR. COEF. =       .122      *
ORIENTATION =     74.297      *
MAJAX      =     52.346      *
MINAX      =     41.432      *
FLIP       =       .209      *
*****

```

```

*****
** 62148450      ** 17761 POINTS FROM 77- V -18 TO 77-VIII-18
INST. DT-5116 DEPTH 5408 M. UNITS = MM/S , DEGREES CELSIUS
VARIABLE ----- EAST ----- NORTH ----- SPEED ----- TEMPERATURE
MEAN      =     43.690         -2.406          73.656          2.155
STD. ERR. =       .405          .305          .244          .165 -3
VARIANCE  =    2913.752        1654.458        1057.607          .484 -3
KURTOSIS  =       2.571          2.338          2.623          1.951
SKEWNESS  =      -.202          -.692E-1          .376          .493 -1
MINIMUM   =    -109.407        -103.708          20.000          2.110
MAXIMUM   =     174.106         114.886          177.334          2.219
-----EAST & NORTH----- * * * * *
COVARIANCE =     134.279      *
CORR. COEF. =      .612E-1*
ORIENTATION =     83.981      *
MAJAX      =     54.110      *
MINAX      =     40.501      *
FLIP       =       .252      *
*****

```

Table 2c

```

*****
** 6215845C      ** 17761 POINTS FROM 77- V -18 TO 77-VIII-18
INST. DT-5114 DEPTH 5418 M. UNITS = MM/S , DEGREES CELSIUS
VARIABLE ----- EAST ----- NORTH ----- SPEED ----- TEMPERATURE
MEAN      =      43.981          2.176          75.953          2.145
STD.ERR.  =      .415           .324           .247           .170 -3
VARIANCE  =    3051.954        1859.560        1081.718        .513 -3
KURTOSIS  =      2.577          2.186          2.535          1.955
SKEWNESS  =      -.306         -.159           .283           .392
MINIMUM   =    -111.376       -103.736        20.000          2.105
MAXIMUM   =     165.511        106.814        178.058          2.201
-----EAST & NORTH----- * * * * *
COVARIANCE =     274.797      *
CORR. COEF. =      .115      *
ORIENTATION =     77.627      *
MAJAX      =     55.787      *
MINAX      =     42.418      *
ELLIP      =      .240      *
*****

```

```

*****
** 6216845C      ** 17761 POINTS FROM 77- V -18 TO 77-VIII-18
INST. DT-5109 DEPTH 5428 M. UNITS = MM/S , DEGREES CELSIUS
VARIABLE ----- EAST ----- NORTH ----- SPEED ----- TEMPERATURE
MEAN      =     41.357          .610E-1        71.674          2.133
STD.ERR.  =      .397           .302           .237           .149 -3
VARIANCE  =    2802.610        1620.480        996.309        .393 -3
KURTOSIS  =      2.628          2.292          2.526          2.756
SKEWNESS  =      -.278         -.191           .292           .890
MINIMUM   =    -112.688       -101.498        20.000          2.104
MAXIMUM   =     161.847         99.584         170.396          2.183
-----EAST & NORTH----- * * * * *
COVARIANCE =     142.233      *
CORR. COEF. =     .667E-1 *
ORIENTATION =     83.235      *
MAJAX      =     53.099      *
MINAX      =     40.045      *
ELLIP      =      .246      *
*****

```


Table 2d

```

*****
** 62178450    ** 17761 POINTS FROM 77- V -18 TC 77-VIII-18
INST. DT-5108 DEPTH 5438 M. UNITS = MM/S , DEGREES CELSIUS
VARIABLE ----- EAST ----- NORTH ----- SPEED ----- TEMPERATURE
MEAN      =      42.116          3.290          71.810          2.126
STD. ERR. =       .390          .301          .229          .114 -3
VARIANCE  =    2698.332        1608.297        934.595          .2321-3
KURTOSIS  =       2.415          2.159          2.350          3.943
SKEWNESS  =       -.282          -.124          .253          1.177
MINIMUM   =    -102.166        -93.826         20.000          2.105
MAXIMUM   =     165.319        104.946        176.400          2.179
-----EAST & NORTH----- * * * * *
COVARIANCE =     189.519 *
CORR. COEF. =      .910E-1*
ORIENTATION =     80.413 *
MAJAX      =     52.253 *
MINAX      =     39.702 *
ELLIP      =      .240 *
*****

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.

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*****
** 6221A450    ** 17733 POINTS FROM 77- V -18 TC 77-VIII-18
INST. V-0183 DEPTH 5418 M. UNITS = MM/S , DEGREES CELSIUS
VARIABLE ----- EAST ----- NORTH ----- SPEED ----- TEMPERATURE
MEAN      =     43.526         -6.186         76.560          2.135
STD. ERR. =       .415          .328          .243          .179 -3
VARIANCE  =    3057.363        1911.001        1049.254          .566 -3
KURTOSIS  =       2.526          1.958          2.458          40.479
SKEWNESS  =       -.332          -.135          .179          2.846
MINIMUM   =    -117.727        -115.311         20.000          2.093
MAXIMUM   =     166.817          98.421        176.522          2.669
-----EAST & NORTH----- * * * * *
COVARIANCE =     232.487 *
CORR. COEF. =      .962E-1*
ORIENTATION =     73.953 *
MAJAX      =     55.702 *
MINAX      =     43.203 *
ELLIP      =      .224 *
*****

```

Table 3

Offsets applied to VACM temperatures m°C

<u>Instrument</u>	<u>Start</u>	<u>End</u>
6217	-.4	-1.2
6216	6.7	-1.7
6215	reference	instrument
6214	13.8	13.8
6213	9.6	5.6
6212	11.5	7.5
6211	23.2	19.2
6221	+11.8	11.8

.5338°C subtracted to form potential temperature compatible with CTD.

Table 4

Vane Stickiness

10 day period
ending 1200

Relative Stickiness

	6211	6212	6213	6214	6215	6216	6217
5/28	-.27	.06	.11	.13	.00	.03	-.07
6/7	-.22	.16	.03	-.02	.03	.00	.01
6/17	-.13	.15	.14	.06	.01	-.08	-.16
6/27	-.02	.06	.31	.03	.11	-.21	-.27
7/7	-.09	-.02	.60	-.07	-.02	-.15	-.26
7/17	-.19	-.06	.54	.02	-.03	-.07	-.22
7/27	-.35	-.07	.64	-.03	-.03	-.01	.14
8/6	-.37	.18	.68	-.03	-.11	-.09	-.26
8/16	-.26	.01	.53	.21	-.19	-.11	-.19

Average Stickiness $(\bar{S}) \approx 900$

Table 5

(Instrument I.D., Compass)		Deviation of compass from mean (bits)					
Data name	Date	0	1	2	3	4	5
6211 (0325, 271)	12/10/76	4	1	0	0	0	0
6212 (5104, 136)	1/26/77	6	0	0	0	0	0
	1/30/78	5	0	0	0	0	0
6213 (5117, 147)	1/ 5/77	3	2	0	0	0	0
	2/27/78	3	2	0	0	0	0
	1/ 8/79	3	2	0	0	0	0
6214 (5116, 59)	5/14/76	2	0	0	0	1	1
	3/ 8/78	3	1	1	0	0	0
	1/ 8/79	3	2	1	0	0	0
6215 (5114, 135)	4/ 5/78	2	2	1			
6216 (5109, 139)	1/17/77	6	0	0	0	0	0
	3/10/78	5	0	0	0	0	0
6217 (5108, 244)	1/19/77	4	1	0	0	0	0
	3/ 1/78	3	2	0	0	0	0

Figure Captions

- Figure 1 Profiles of potential temperature, salinity and nephels (turbidity) from the first downtrace of OCEANUS 31, station 38.
- Figure 2 Diagram of Moorings 621 and 622.
- Figure 3 Time series of filtered current vectors.
- Figure 4 Horizontal kinetic energy spectra and temperature spectra from the seven instruments on Mooring A.
- Figure 5 Progressive vector diagram for filtered daily averaged current data.
- Figure 6 Composite plots of velocity and potential temperature data from Mooring A.
- Figure 7 Composite plots of velocity and temperature data from Mooring B.
- Figure 8 1-day differential velocity. Each arrow is the vector difference between the 1 day mean velocity for a given instrument and the average of this velocity over all instruments for the same time period. Each arrow is rotated so that this vertical average velocity points horizontally and to the right. The height of each arrow indicates the height of the instrument off the bottom (left hand axis). Its position on the bottom axis indicates the central time of the 1 day average. A synthetic instrument has been inserted at 75 m by linear interpolation.
- Figure 9 Compass records from top 4 instruments showing rapid mooring motion on July 19 and 20.
- Figure 10 Vane records for all instruments at a) beginning and b) end of experiment.
- Figure 11 Bearing minus direction records for all instruments for 3 periods. (Upper panels) and speed from 6211 during same periods. Bearing minus direction is a sensitive indicator of directional noise. Notice higher variance when speed is low a) and c); when speed exceeds a threshold b), and in 6213 in c).

Figure 1

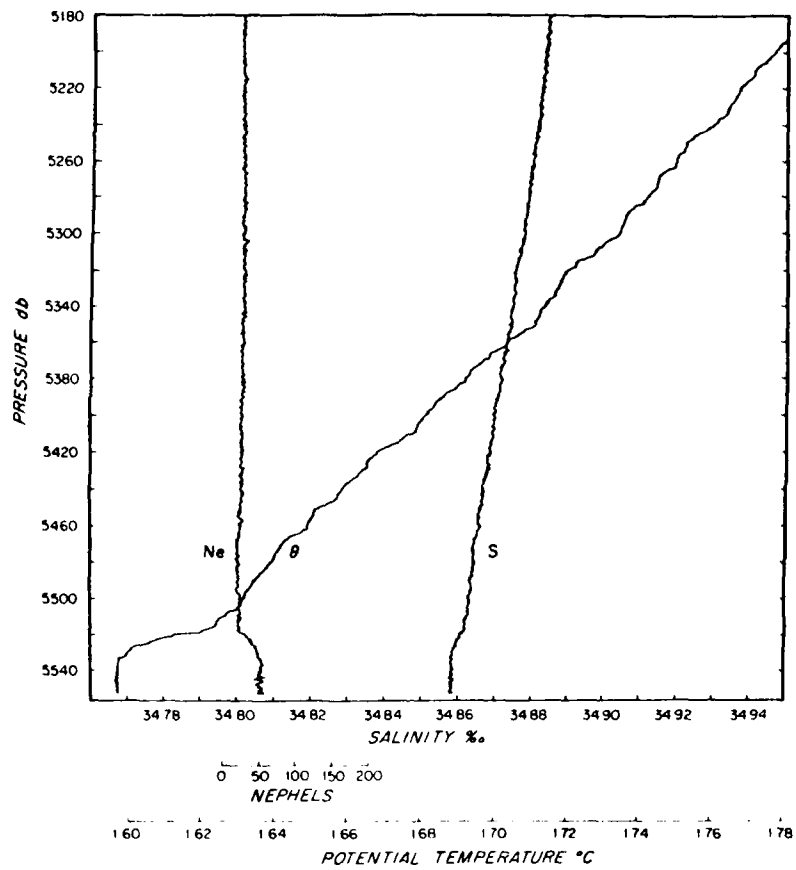


Figure 2

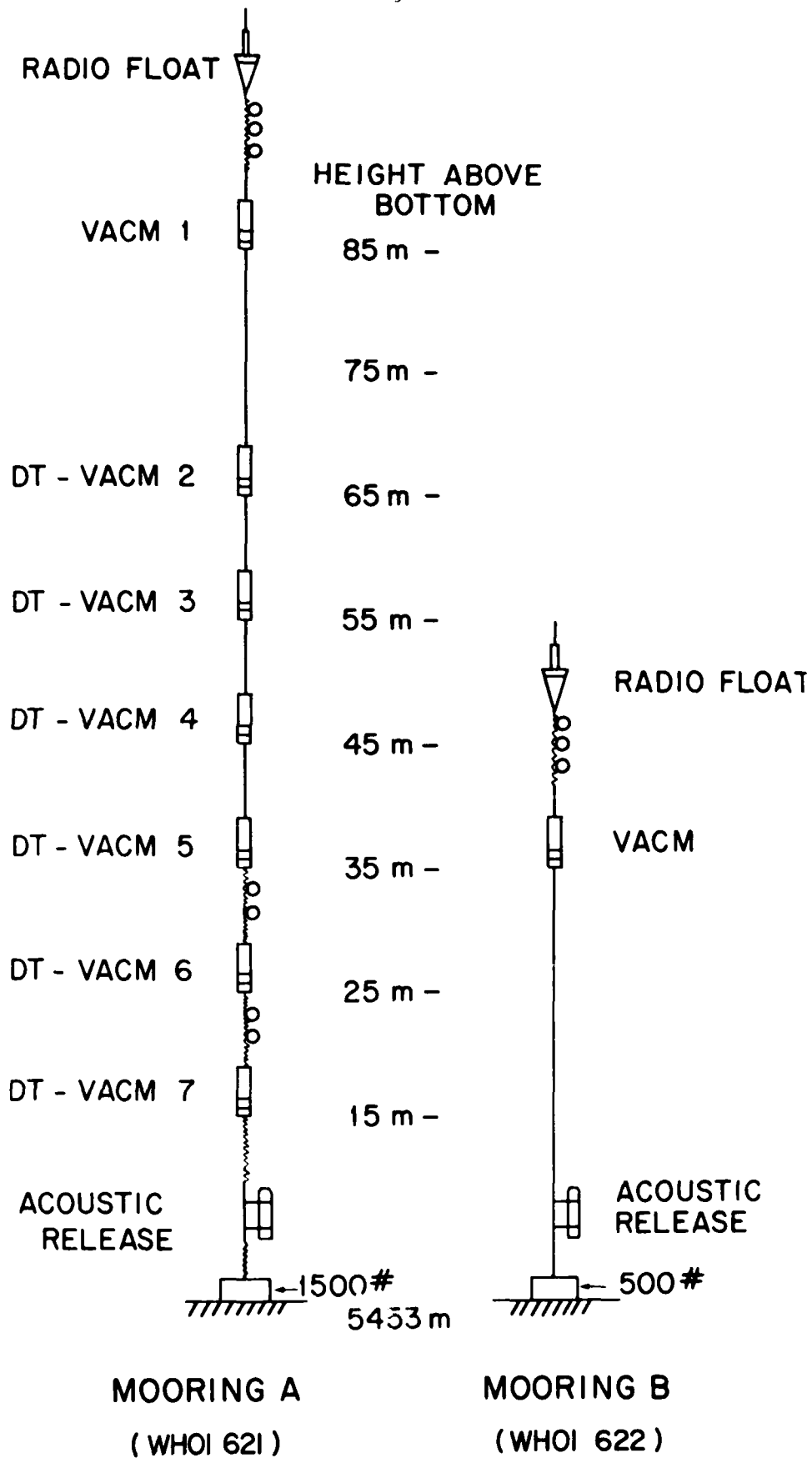
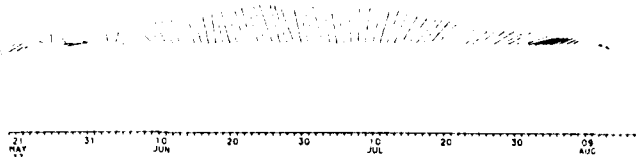


Figure 3

621810024
5418 H



621810024
5368 H



621810024
5368 H



621810024
5368 H



621810024
5418 H



6215010024
5418 H

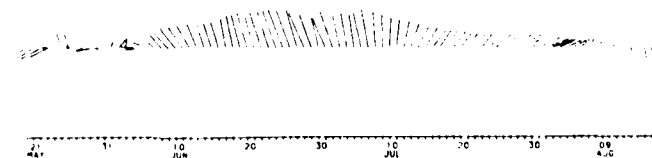


6216010024
5428 H



6217010024
5438 H

200
150
100
50
0
50
100
150
200



200
150
100
50
0
50
100
150
200

Figure 4a

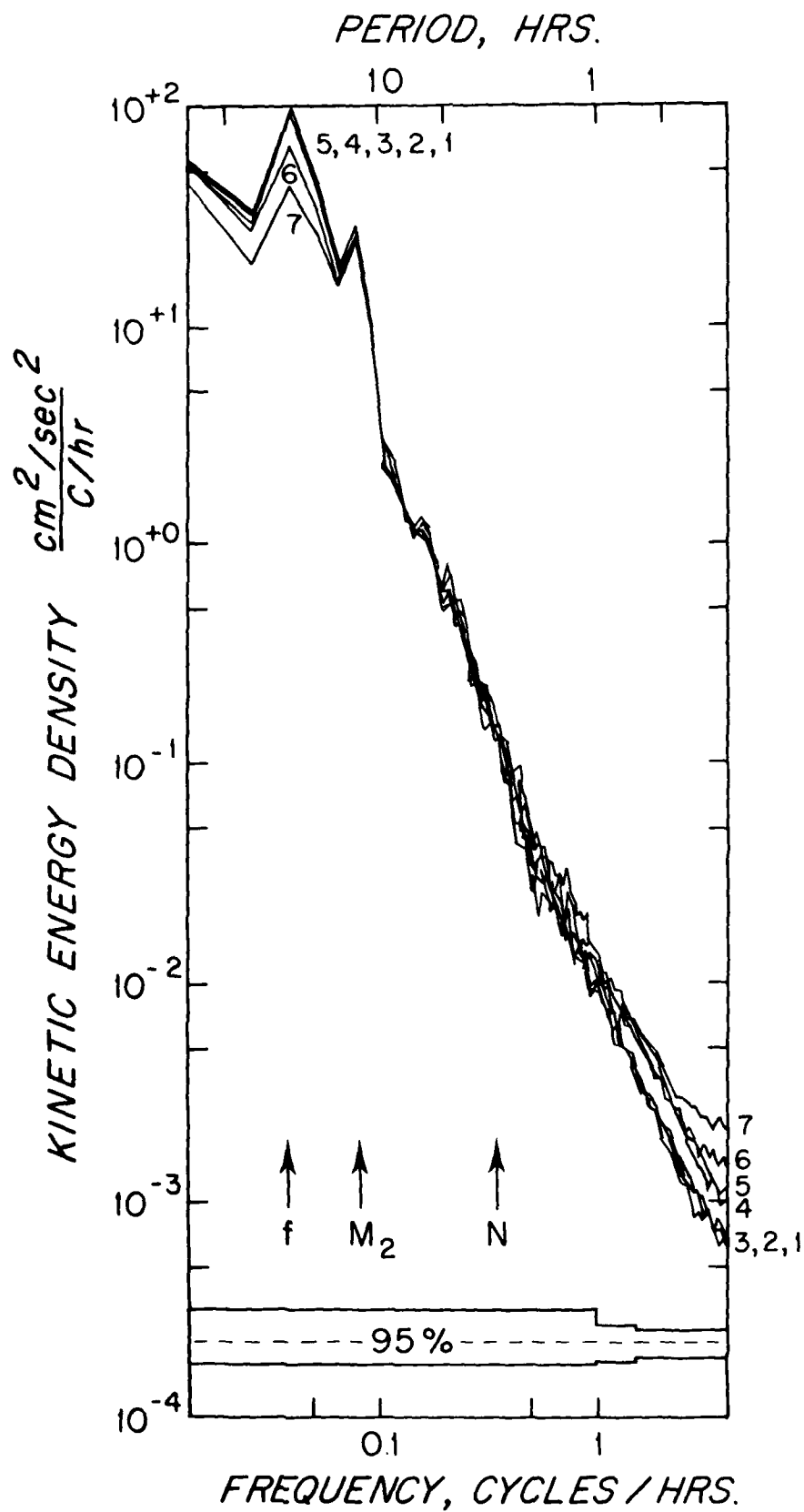


Figure 4b

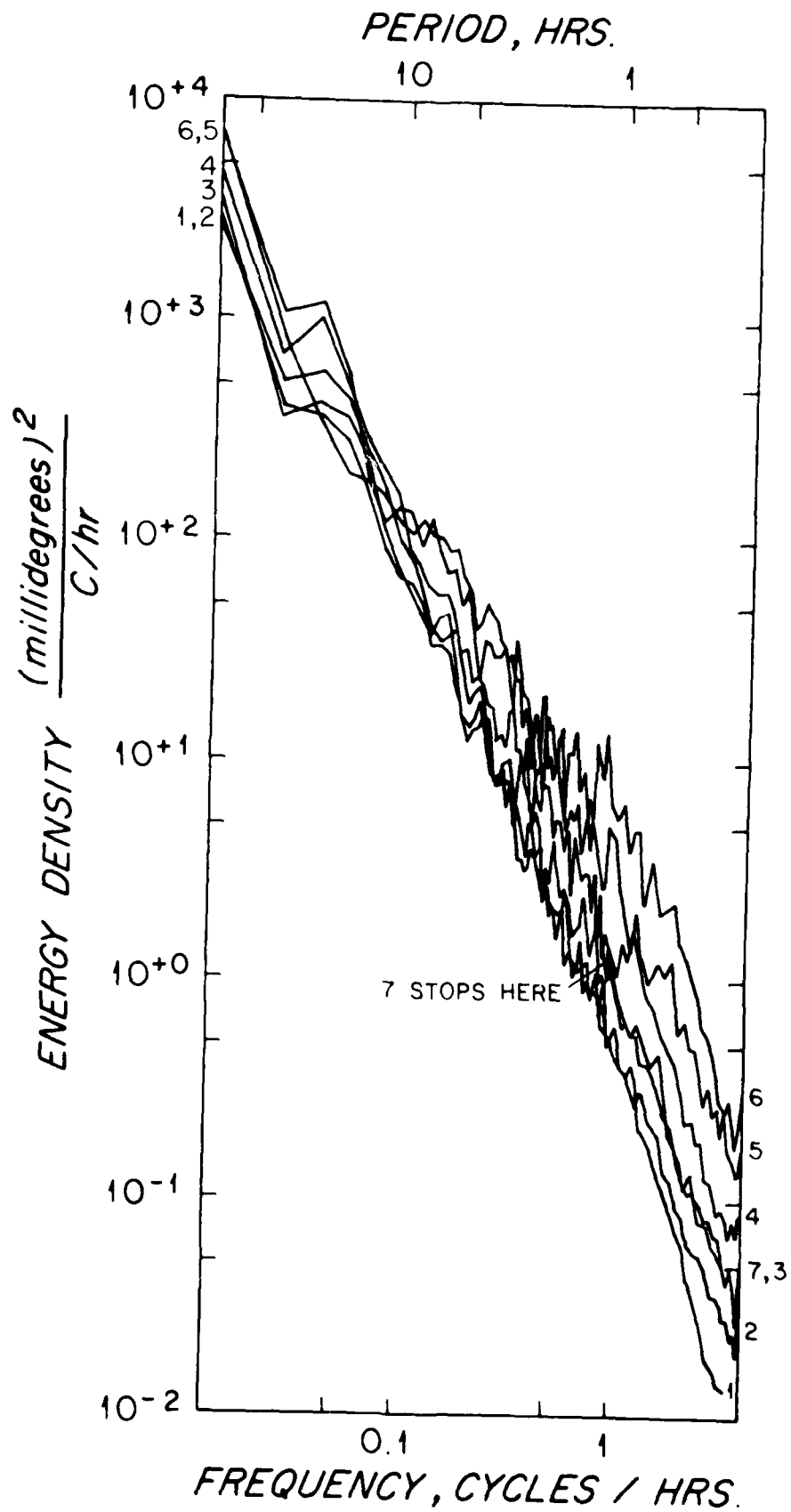


Figure 5

62218IDG24

5418 M

6211CIDG24

5368 M

6212CIDG24

5388 M

6213CIDG24

5398 M

6214CIDG24

5408 M

6215CIDG24

5418 M

6216CIDG24

5428 M

6217CIDG24

5438 M

0 10 20 30 40 50
KILOMETERS

11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

Figure 6a

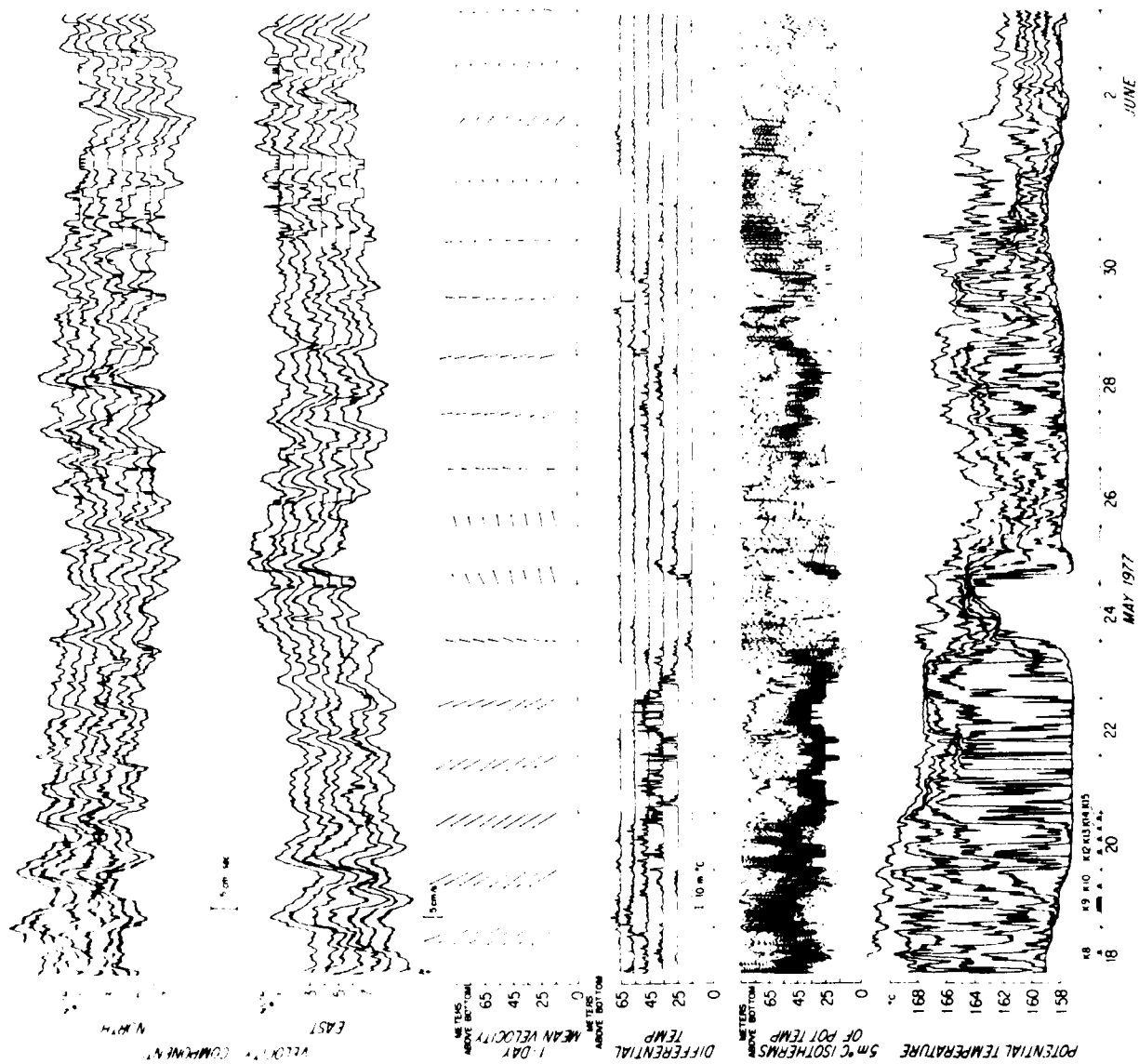


Figure 6b

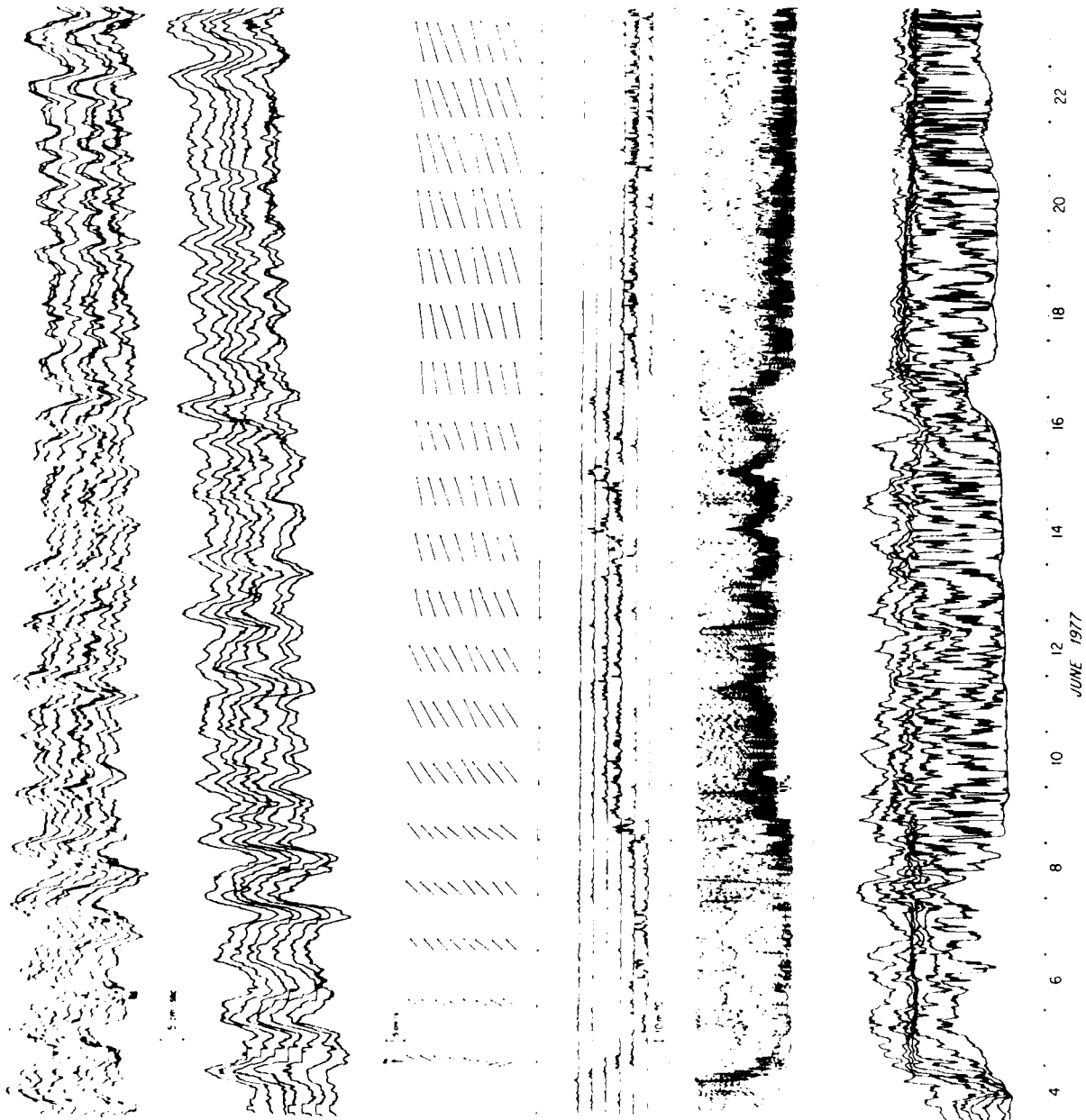


Figure 6c

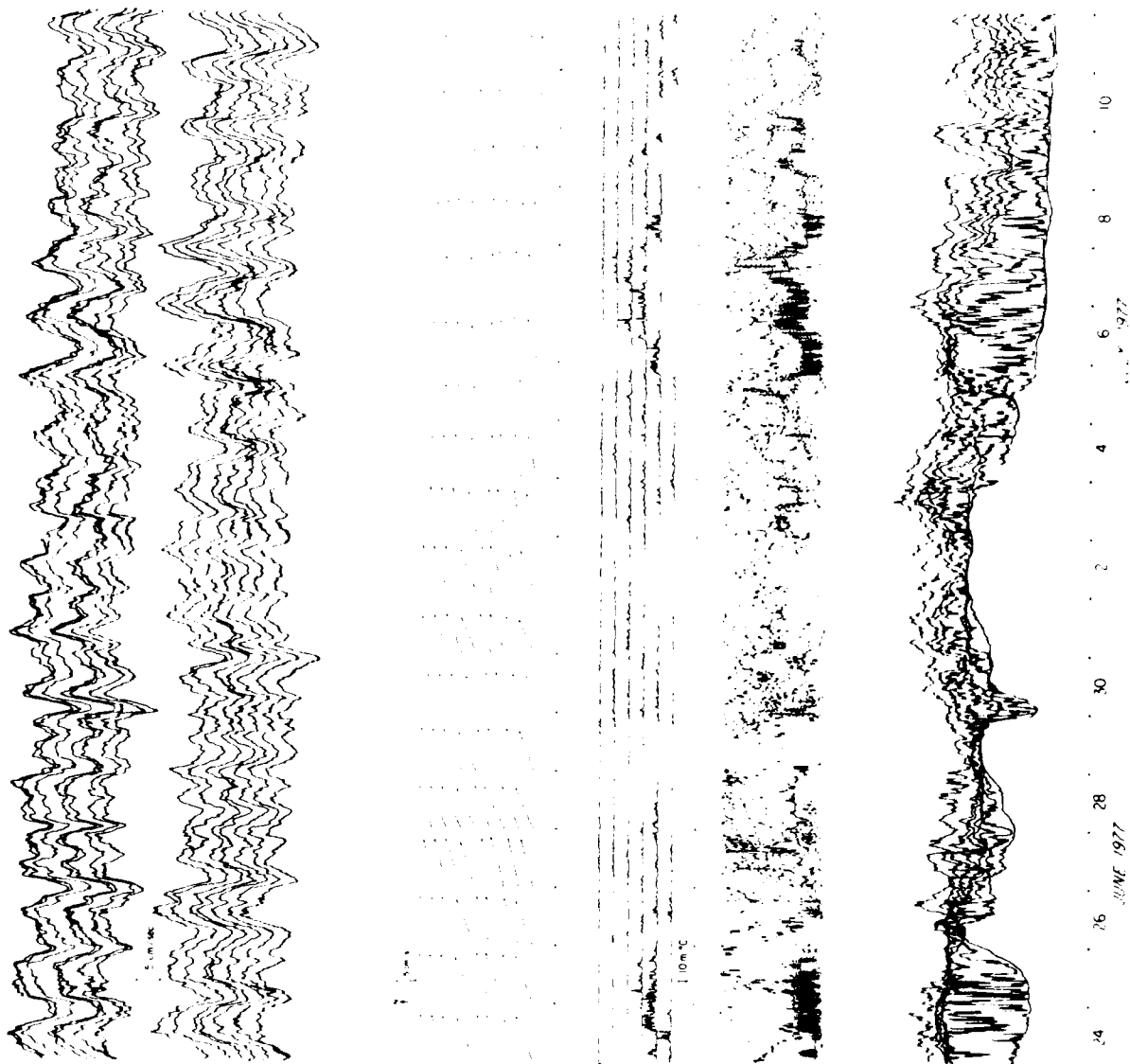


Figure 6d

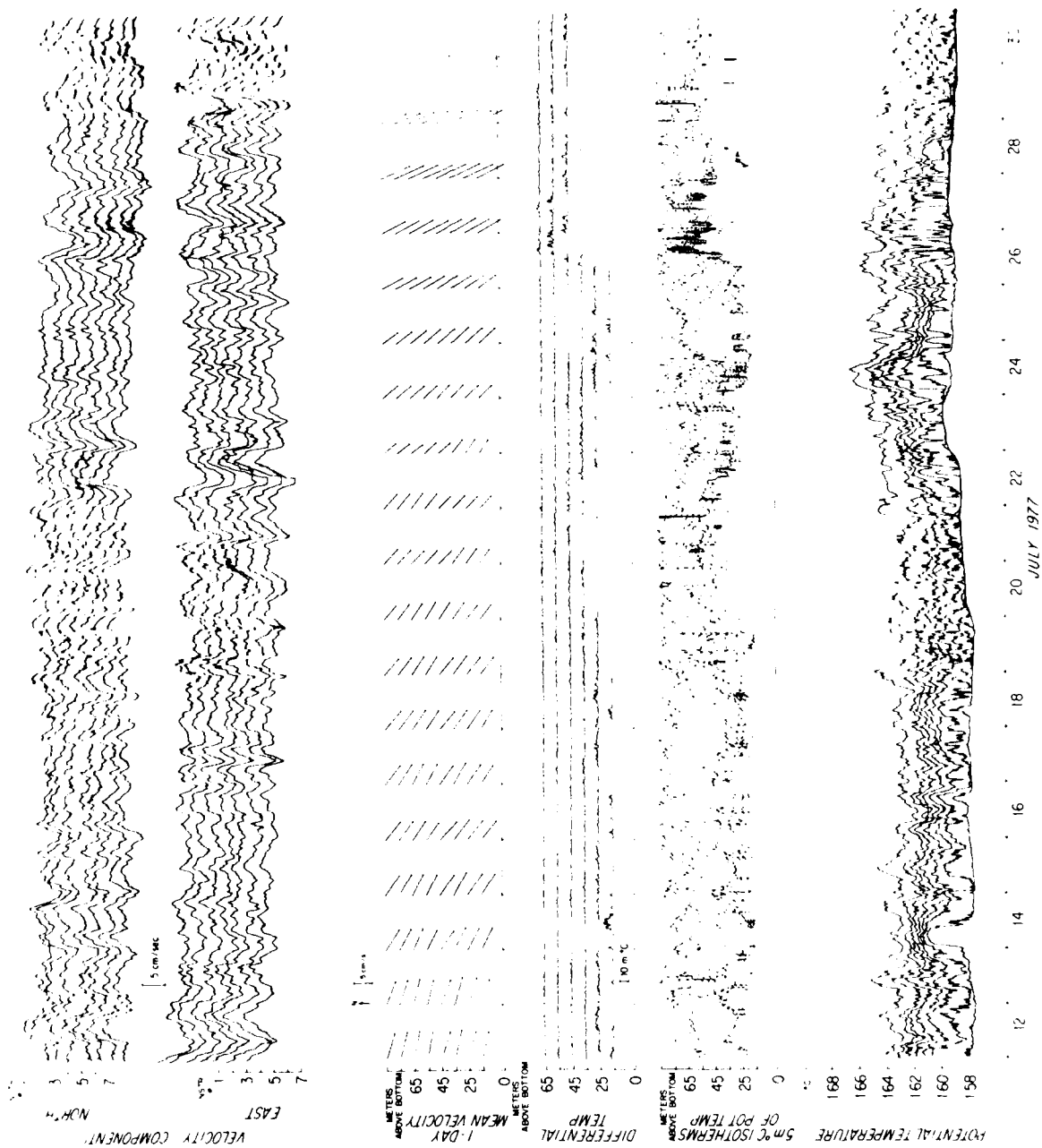


Figure 6e

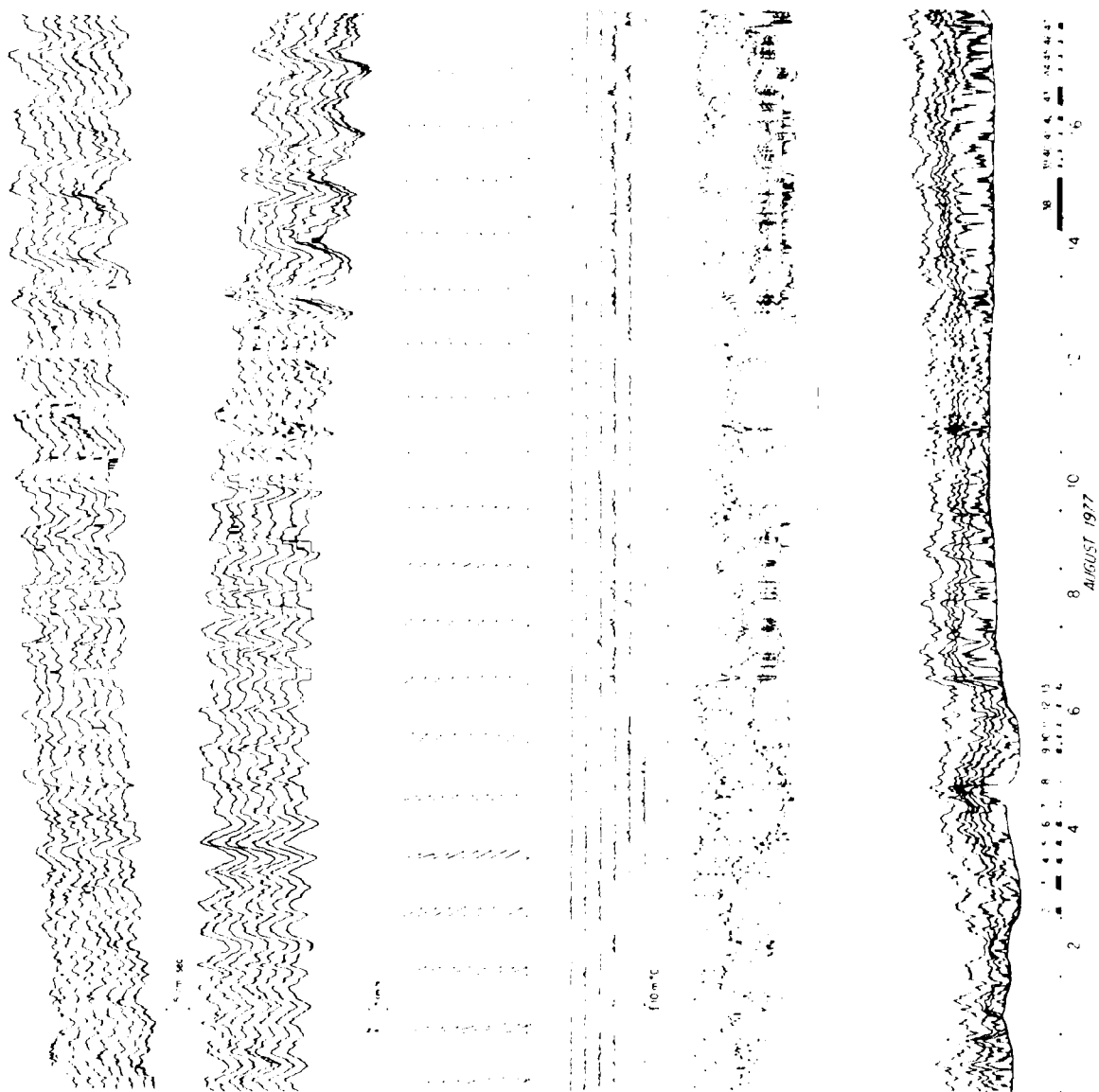


Figure 7a

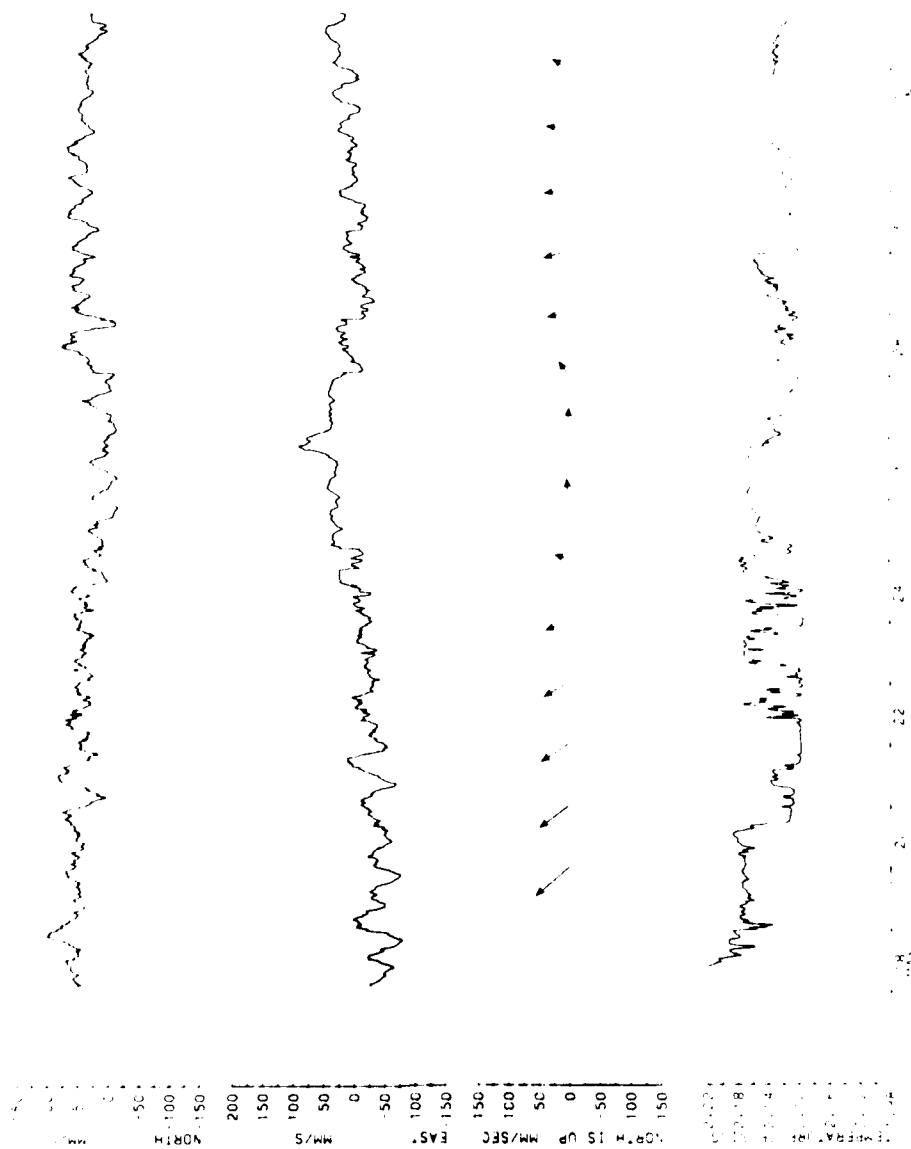


Figure 7b

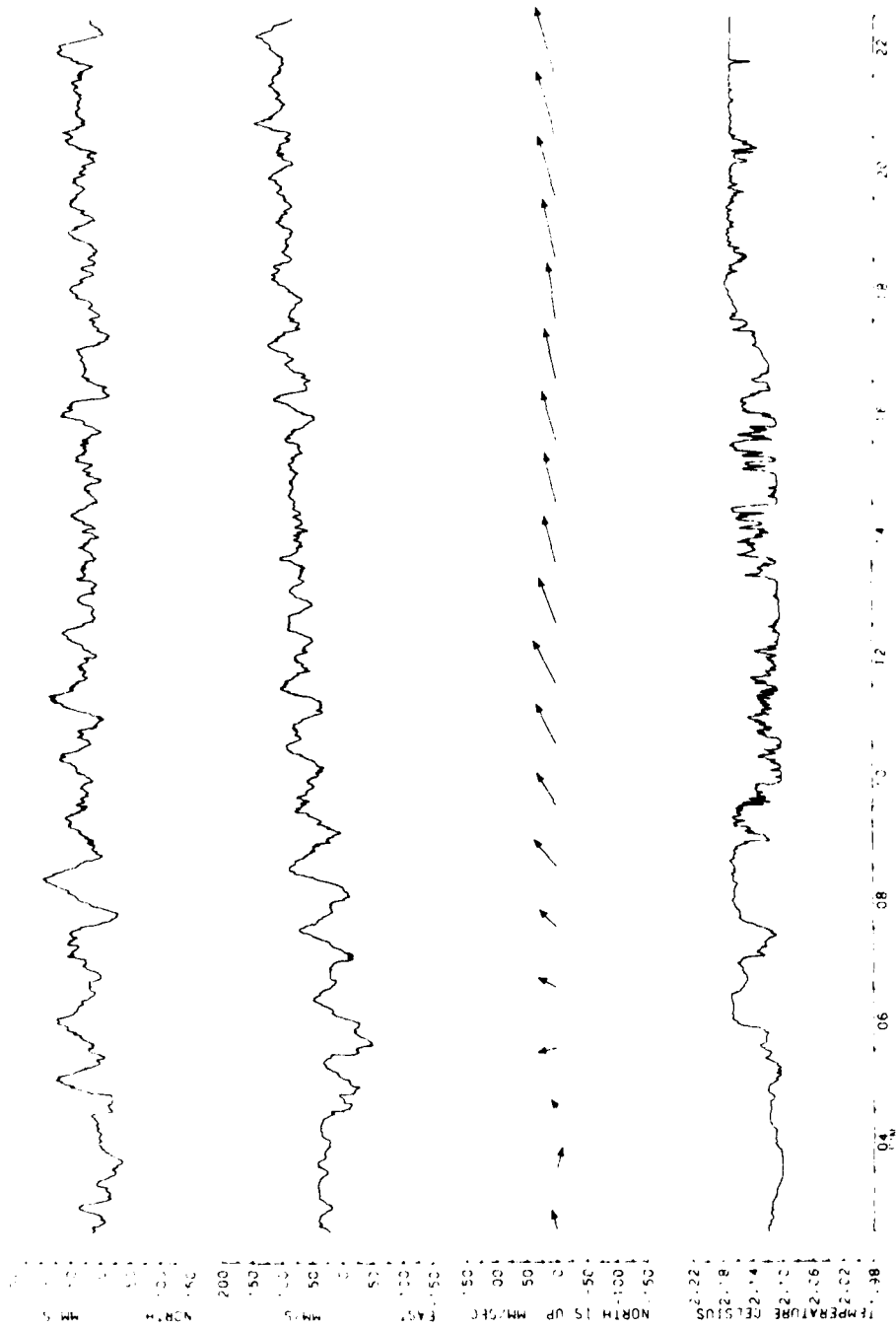


Figure 7c

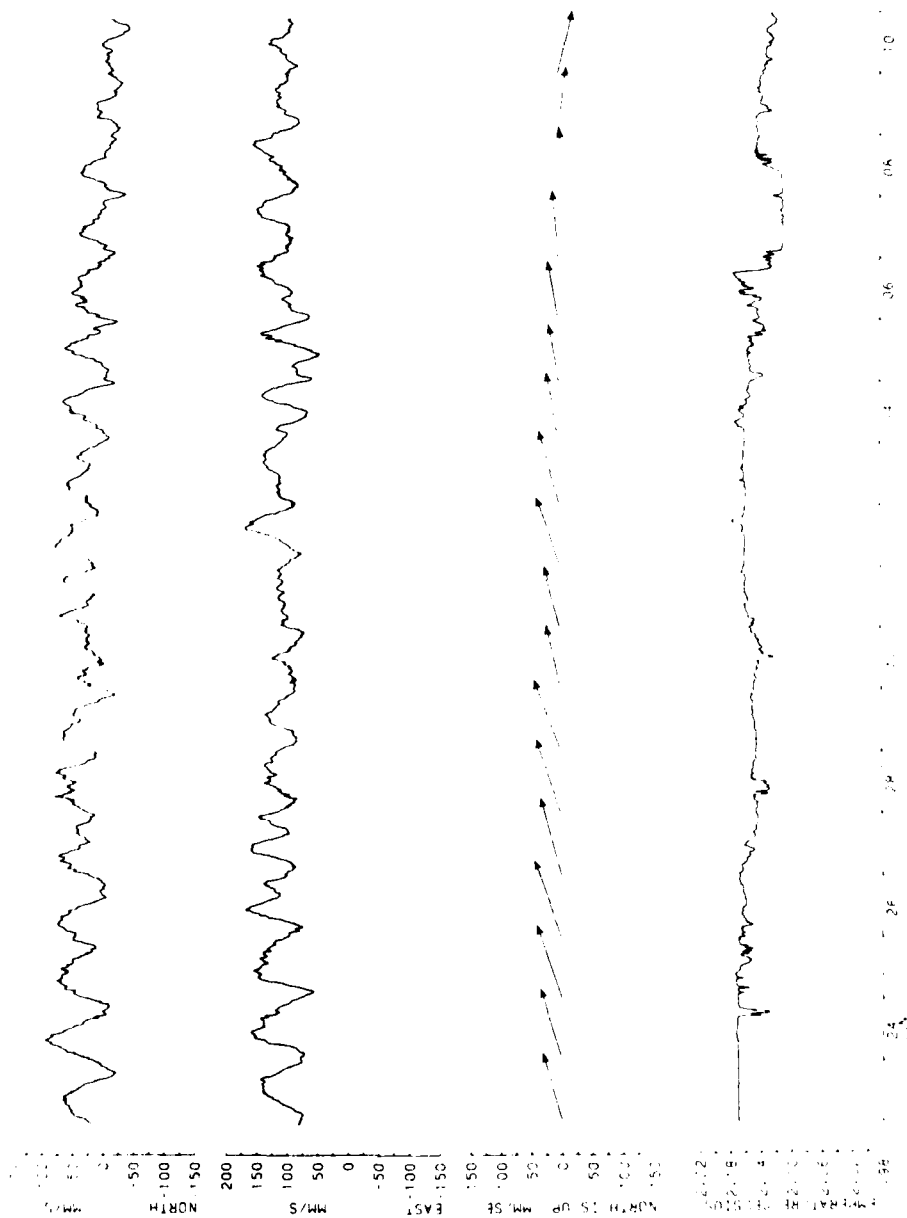


Figure 7d

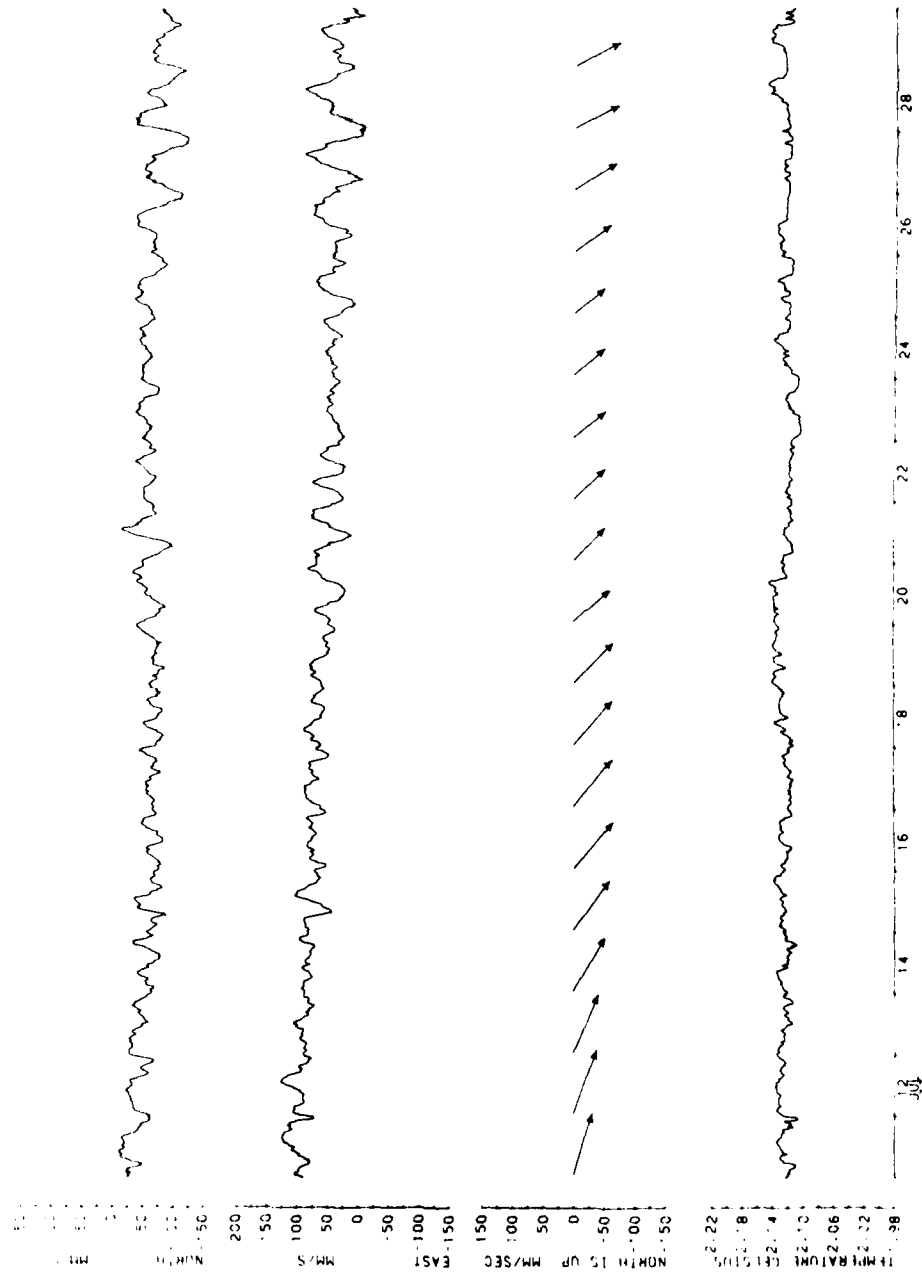
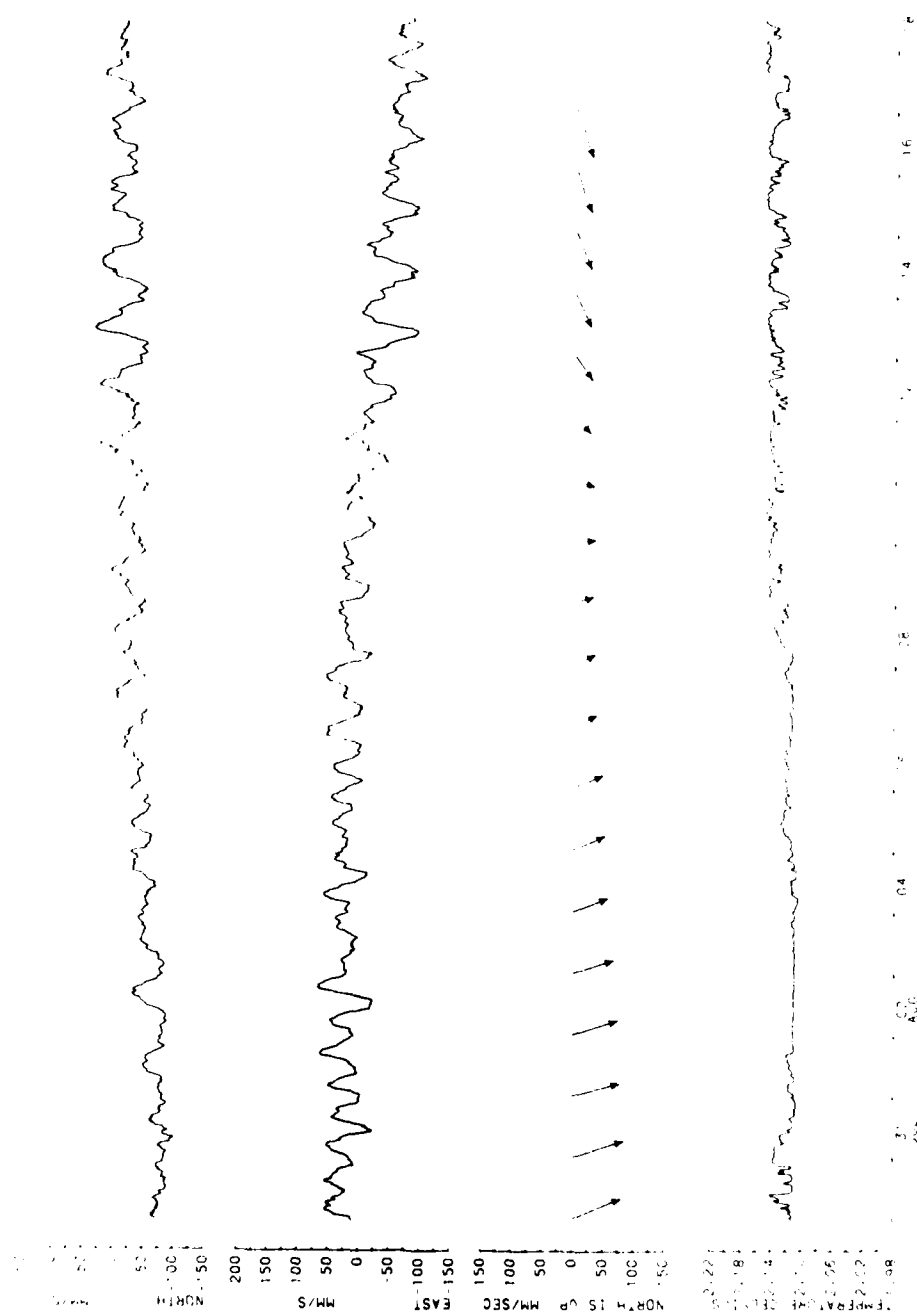


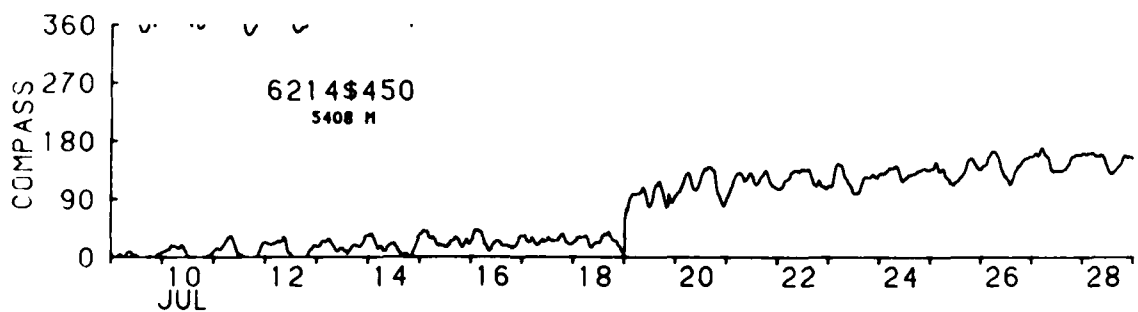
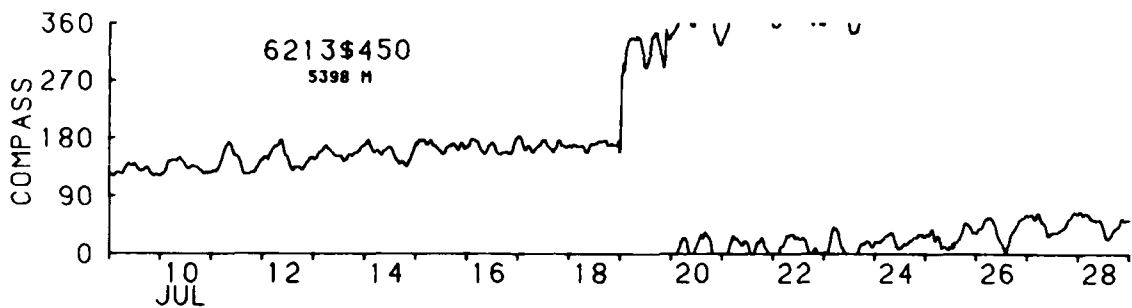
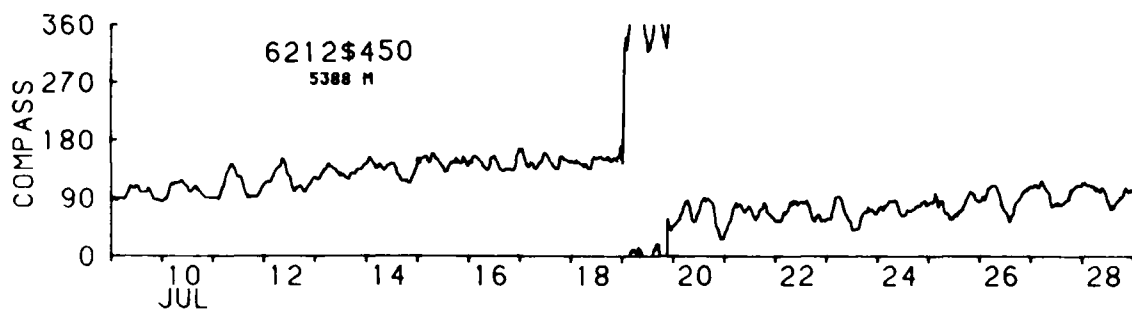
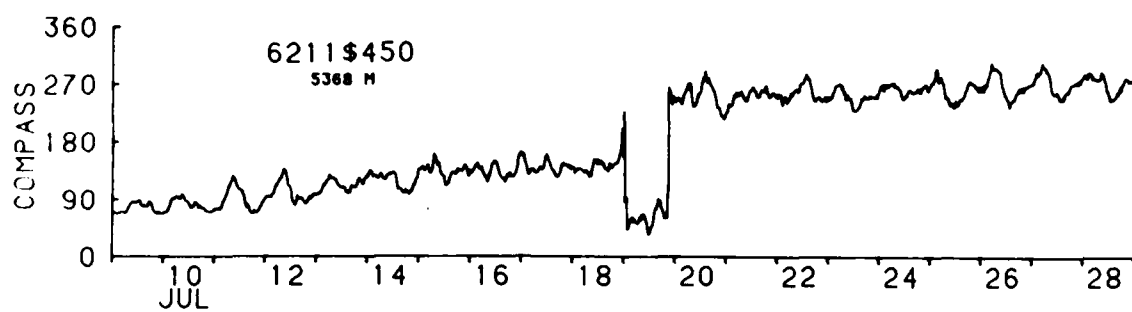
Figure 7e



8



Figure 9



1977

Figure 10

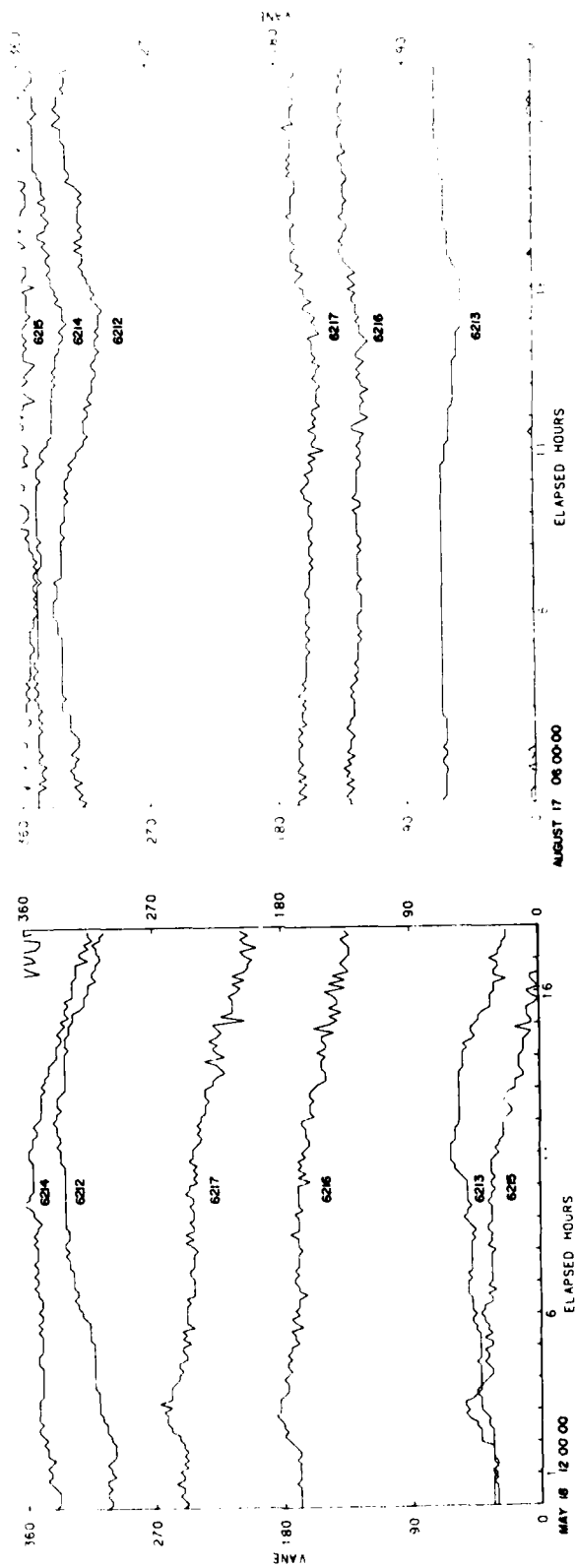
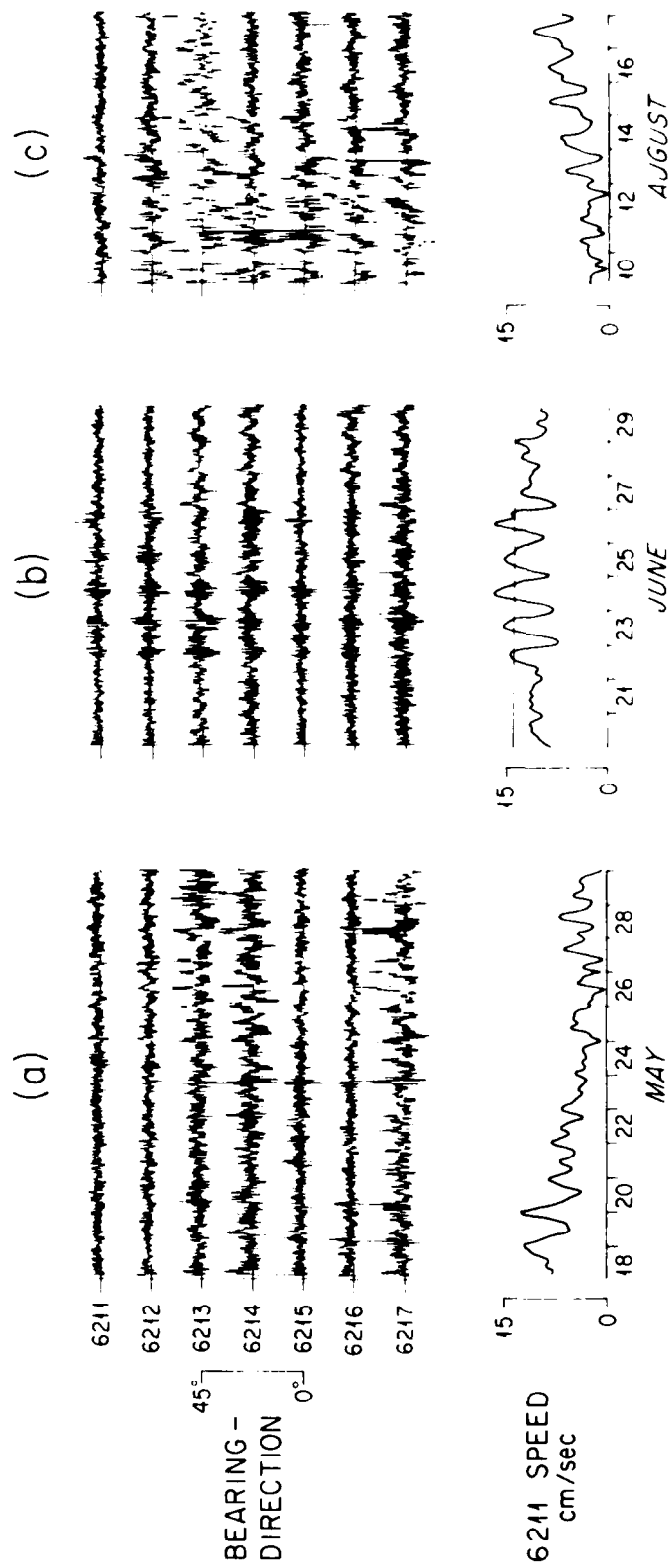


Figure 11



Office Memorandum • WOODS HOLE OCEANOGRAPHIC INSTITUTION

TO : Larry Armi, Dick Payne

DATE: April 7, 1978

FROM : Jerry Dean

SUBJECT: VACM Rotor Low Speed Calibrations, Station 621 BBL DT-VACMs

Rotor calibrations at speeds between 0 and 10 cm/sec have been done and the instruments returned to the CM shop for JASIN prep.

We ran two calibrations for each instrument, one with a cage gap between posts leading into the flow, and one with a cage post leading into the flow. Each curve shown in the figures and tabulated is a linear regression fit to at least 7 points, and each point is the average of at least 5 readings at each speed. The attached figures show the spread of data. Typically, the post leading data lies on the high side of the mean at threshold and the gap leading the low side of the mean threshold.

The mean threshold is 0.7 cm/sec lower than the expression we now use in data reduction with the exception of DT-5114 which falls on our presently used calibration.

At 10 cm/sec the mean of these calibrations falls on our present curve at 1.77 rotor counts/sec. Therefore, I would recommend for your special calibrations you use

Intercept $b = 1.30$ cm/sec

Slope $a = 39.44$ cm/rev

for all data below 1.77 counts/sec except for DT-5114, for which you should use the present Buoy Group calibration.

DT-VACM	Intercept b(c/s)	Slope a (cm/rev)	Counts/sec @ 10 c/s	Correlation
5104, post	1.34	37.53	1.85	.991
5104, gap	1.16	38.63	1.83	.998
5108, post	1.53	39.31	1.72	.999
5108, gap	1.31	40.6	1.71	.999
5109, post	1.44	39.48	1.74	.993
5109, gap	1.14	41.14	1.72	.999
5114, post	2.23	35.76	1.74	.992
5114, gap	1.84	39.12	1.66	.997
5116, post	1.45	38.56	1.77	.994
5116, gap	1.17	38.80	1.82	.999
5117, post	1.36	39.39	1.76	.995
5117, gap	1.35	37.58	1.84	.997
Mean				
(except 5114)	1.30	39.44	1.77	
Standard dev(s)	0.15	1.23		

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(REVISED NOVEMBER 1978)

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